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Joint Soviet-American Working Group for
the Study of the Natural Environment

USSR Academy of Sciences and
NASA Office of Applications



National Aeronautics
and Space Administration

**Scientific and Technical
Information Office**

1977

JOINT DOCUMENT CONCERNING GEOLOGICAL STUDIES
FROM 1971-1975

In January 1971, as a result of talks between the President of the USSR Academy of Sciences, Academician Keldysh, and the Acting Administrator of NASA, Dr. Low, NASA and the Academy signed an agreement on cooperation in space research. One of the areas covered by the agreement was to study the possibilities of conducting coordinated space research in the field of remote sensing of the natural environment.

In order to organize this research, a joint Soviet-American working group on natural environment was established. The working group was called upon to facilitate cooperation in a number of major directions, including:

- a. discussions and the exchange of scientific information on the use of space technology for investigating the natural environment;
- b. studies of various methods for measuring parameters of the natural environment and interpreting the results of these measurements;
- c. exchange of results of coordinated research over selected sites on the Earth's surface.

More specifically, the working group was asked to, among other things:

- a. conduct reviews and discuss investigation results;
- b. recommend mutually agreeable procedures for conducting coordinated programs;
- c. recommend the parameters to be measured and the kind of data to be obtained as well as forms and schedules for data exchanges;
- d. recommend methods and procedures for the joint review and consideration of such data in symposia open to other countries.

In August 1971, the first meeting of the Joint Working Group on the Natural Environment took place in Moscow, at which the subjects of geology, hydrogeology, and archeology were selected among other topics to be jointly investigated by scientists of both countries.

It was recommended that the results of these experiments be exchanged in the form of technical reports containing conclusions, analysis methods, and original data with sufficient completeness that the analysis could be repeated by other investigators.

Two analogous sites and a number of complementary ones were selected by both sides. As investigations progressed, the geologic objectives were narrowed by mutual agreement and became more topical as opposed to regional; thus, greater flexibility was adopted with respect to site location. The major sites under the study by the United States included the States of Nevada, California, and Alaska, with optical filtering work largely undertaken in the Front Range province of Colorado. The major sites in the USSR for study are the Balkhash, Tien Shan, Caucasus and Ustyurt regions.

In accordance with recommendations of the 1971 meeting, an exchange of information on the research conducted in the USSR and USA in the respective fields was conducted during the working group meeting in 1972 in Washington (Anderson, 1972, 1, 2; Gawarecki, 1972; Hamilton, 1972; Lowman, 1971; Komarov, et al, 1972; Trifonov, 1967; Khodarev, et al, 1975). Further delineation of studies of mutual interest was also achieved.

As a result of these actions, at the next meeting in 1973 (Moscow, USSR), a joint conclusion was reached that a number of similar interpretation techniques were being used by the U.S. and the USSR to interpret geological features from photographs and radar images (Bashilov, et al, 1973; Gendler, et al, 1973, Dolivo-Dobrovolskiy, Kobetz, 1973; Trifonov, et al, 1973; Carter, 1973, Fischer, 1973; Komarov, et al, 1973 a, b; Sakhatov, 1973; Strel'nikov, et al, 1973; Gawarecki, 1973; Gummerman, 1973; Morrison, 1973). On the basis of the information exchange, and discussion of the projects agreed to in 1971, three specific objectives were jointly selected for future coordinated research.

They were:

1. To develop aids for detection and analysis of tectonic lineaments expressed on space and aerial photographs through the use of diffraction images and spatial filtering.
2. To define in detail recognition methods for tectonic linears on space images with the long-range objective of developing a classification system for linears.
3. To undertake studies designed to further understand the relationship between structural features visible on space images and previously known geologic subsurface structures.

Because of lack of corresponding interest in archeology within the geology panel, this subject was dropped as a topic of joint study. Also, the problems pertaining to the subject of hydrogeology were transferred to the "Water, Snow, and Glaciology Panel."

At the working group meeting of 1974 (Washington, USA), initial results of research in the three selected objectives were discussed (Astakhov, Yermenko, 1974; Brusnichkina, Gusev, 1974; Dolivo-Dobrovol'skiy, 1974; Dolivo-Dobrovol'skiy, Strelnikov, 1974; Komarov, et al, 1974, 1, 2; Lukashov, 1974; Makarov, et al, 1974; Martirosyan Sakhatov, 1974; Shultz, 1974; Yakovlev, et al, 1974; Yakovlev, Skublova, 1974; Lathram, 1974; Lattman, 1974; Lowman, 1974, Offield, 1974; Rowan, 1974). Both methods of study and theoretical and practical value were stressed by both sides; it was recommended that research, discussion, and information exchange be continued in these fields.

During the 1975 meeting (Moscow, USSR) (where the geology panel did not meet) the two working group chairmen decided to ask this panel to prepare a report on completed work and to present it to the 1976 working group meeting. A meeting of the geology experts took place in the U.S. in October-November 1975 during which a draft report was prepared for presentation at the 1976 working group meeting. This report was approved by the co-chairman at the 1976 meeting.

SPATIAL AND DENSITY FILTERING

At the 1973 working group meeting in Moscow, Soviet and American specialists agreed to conduct joint studies on the application of optical image filtering for the purpose of isolating lineaments of different orientation by using both simple raster Ronchi grating and optical coherent systems.

Use of diffraction images of photographs and line maps of the terrain can facilitate the detection and analysis of alignment of image detail, such as geologic lineaments, or preferred orientation of "grain" on topographic magnetic, and gravity maps. This analysis may be performed with the aid of Ronchi gratings or coherent light from a laser. A Ronchi grating consists of glass or transparent plastic on which precision dark lines have been ruled at discrete intervals. To determine preferred orientations, the grating is placed a few centimetres in front of the eye or a projector and rotated. Alignments are noted, their orientation measured, and the process is repeated until all alignment orientations have been observed. A laser and high quality lenses, precisely aligned on an optical bench, can be used to perform the same analysis more precisely by inserting disc- or wedge-shaped filters into the diffraction image plane.

In this connection, both sides studied the possibility of using the raster method, based on the application of the Ronchi grating, and developed the method and constructed typical geometric models of prominent geological lineament trends, both straight and curvilinear. These studies showed the value of these methods for isolating trends of selected geologic linears. A theoretical and methodological basis has been established by scientists in the US and USSR for using photographic filtering of raster (Ronchi) and laser techniques, and for using a combined system employing raster, density, and photographic processing techniques. In the course of the development of methods for optical filtering by means of a laser, there arose the possibility of quickly obtaining rose-diagrams of lineaments with the aid of a photometric diffractive image taken with a dotted filter.

Komarov and others (1974) added evidence that the photographic methods of directed transmission of images are simple and do not require expensive equipment. They can be used by many geologists and other specialists to extract the orientation of selected straight and curved linears from the images. For this purpose, filters with both selective transmission and scattering characteristics were used. Geological formations and structures, such as fracture alignments and curvilinear volcanic centers, commonly occur as simple geometrical patterns, and can be selectively extracted or enhanced by using special rasters, including Ronchi gratings, concentric circles, and radial lines. A raster system using the Ronchi grating principle was used to isolate examples of selected directions of geological linears.

Komarov and others (1975) undertook experiments to test methods of photographic filtering (equidensity, methods of defocussing or "softening" optical masks, use of rasters, and other methods) can be used in a combined system of photographic transformation. The combined system uses various combinations of filters with the original image and with each other.

Not only does this approach permit depiction of geological structures shown on the original images but provides additional geological information. The theoretical and methodological bases of the photographic transformations system have been worked out and some results are as follows:

- Generalization of all image elements with the same tonal density;
- Compilation of scene characteristics in terms of isolines;
- Identification of intersections of multiple lineaments;
- Compilation of dynamics of the natural objects through the analysis of repetitive imagery of the same area.

Efimova and others (1975) provided further evidence that image processing with coherent light may be conducted in two directions:
(a) simple filtering, which enhances the expression of lineaments and isolates selected ones from the rest of the original image;
(b) quantitative analysis of lineaments (determination of predominant directions production of rose-diagrams of lineaments). In order to have an objective picture of distribution of lineaments in a study area, the thrust of their efforts was directed to the development of the methods of spectral analysis of the diffractive pictures obtained with a laser. In this connection, instead of a sector wedge filter, a dotted filter was proposed and used, permitting production of rose-diagrams more precisely. The effectiveness of this approach was demonstrated in the processing lineaments on the space image of the Caucasus and the lineament pattern of the Ukrainian shield.

Offield (1974) noted that a few major faults in the Colorado Front Range were enhanced by laser optical filtering of images, but that most linear elements were too widely spaced in this area of laser enhancement to be effective. Moreover, wedge shaped spatial filters caused spurious shadow artifacts which obscured the resulting image and made interpretation of real features extremely difficult.

Offield (1975) working in parallel with his Soviet colleagues, also modified wedge filters used previously by constructing them with curved, rather than straight edges, and by photographing them slightly out of focus to "soften" the edges. This modification effectively avoided the edge-diffraction effects met previously, and permitted inexpensive enhancement or removal of selected linear trends in aeromagnetic maps, fault maps, and images of the Colorado Front Range; and Skylab imagery of the Mississippi Embayment: and an aerial photograph of the Colorado Plateau near Moab, Utah. Offield (1975) took a new approach and used television edge enhancement techniques; he concluded that although laser filtering removes obscuring trends, it does not provide as much enhancement of other directions as does the television enhancement.

In summary, investigations in the area of spatial filtering, performed by both sides, have demonstrated a potential for using simple methods of image transformations. They enable specialists to extract and analyze linear trends and other information from imagery and line maps. These methods have been developed for their practical application. As regards further work in this area, the methods of photographic transformation of the images and their analysis are applicable to geological problems.

Optical filtering by means of a laser and its effectiveness must be examined in the view of advances in the area of edge enhancement and electronic image filtering. The method for constructing rose-diagrams showing orientation of lineaments from a diffraction picture should be included in comprehensive analyses of geological data.

Although the U.S. side recognizes the common progress made in the analysis of diffraction images and optical filtering, the U.S. Geological Survey is deferring additional optical work in this area in order to examine approaches utilizing computer compatible digital techniques.

LINEAR AND RING FEATURES OF SPACE PICTURES AS ELEMENTS OF DEEP STRUCTURE OF LITHOSPHERE

During the progress of the investigations, it has become apparent to scientists in both countries that Objectives 2 and 3, that were agreed to at the meeting of 1973, are closely related. Both of these topics are discussed together in this section of the report.

I. Principles and Methods of Investigations

Images of various scales and resolutions were used for studies of the geological expression of the linear and ring features in space pictures:

- TV and scanner images from the satellites, "Meteor," "Nimbus," NOAA, with resolutions on the order of 1 km. Reduced pictures of the larger scale pictures were used occasionally in place of the original data.
- Scanner and photo images from Landsat and the manned spacecrafts, Soyuz, Salyut, and Skylab, with spatial resolutions of 30-300 m. Small-scale (1:1,000,000 to 1:2,500,000) photo mosaics of space images covering distances of 1,000 or more km were prepared to facilitate identification of large structural features.
- Aircraft photographs and radar images with spatial resolutions on the order of 10 m were used in some areas for the study of structural details interpreted on space images. Lineaments and apparent ring structures, as interpreted on space pictures of the various scales, were compared with existing bore-hole data and with geology, geomorphology, mineralization, and subsurface information. Aeromagnetic, gravity, and deep seismic data were used to determine the deep structural models, as well as maps showing the relief of the surfaces of various deep layers such as the consolidated basement, Conrad and Mohorovich surfaces. Seismological data included location, depth, magnitude and earthquake foci, as well as zones of abnormal absorption and velocity variations of the seismic waves.

- The ability to identify geologic features depends on albedo changes and shadows caused by topography and variations in solar illumination. Florensky, et al (1975) calculated correlation coefficients of the geometric characteristics of the features interpreted from imagery and correlated them with geological and geophysical data. Another approach emphasized by Lathram (1974) and Rowan (1974) is to compare the location of geophysical anomalies with features mapped from space imagery. This comparison must include trends and locations of significant geophysical anomalies. Various amounts of smoothing of gravity and magnetic data are required to compare surface expressions to deep crustal and upper mantle structures. More smoothing is required for deep structures than shallower structures.

Interpretations of linear and ring features were conducted in both the U.S. and USSR. Geological mapping, special studies of the fault morphology, and magmatic and volcanic activity, geomorphology, modern and recent deformations of the Earth's surface were present in the areas studied. The areas of study were selected to encompass different geological structures.

In the USSR, initial effort was directed at four areas:

- The Tien Shan region is an area of high neotectonic activity and predominant compression on the boundary of the Indian-Pamir and Eurasian lithospheric plates (Trifonov, et al, 1973; Strelnikov, et al, 1973; Makarov, et al, 1974; Makarov, Solovieva, 1975; Panin, Scobelev, 1975; Skublova, 1975).
- The Caucasus region is an area of alpine tectogenesis and the extensive recent compressional deformation and lateral displacements on the boundary of African, Arabian, and Eurasian plates (Trifonov, et al, 1973; Sakhatov, 1973; Brusnichkina and Gusev, 1974; Makarov, et al, 1974; Martirosyan and Sakhatov, 1974; Anan'in and Trifonov, 1975; and Scariatina, 1975).
- The Balkhash region is an area of complicated palaeozoic tectogenesis and magmatism and weak neotectonic activity (Komarov, et al, 1973; Dolivo-Dobrovolskiy and Kobets, 1973; Dolivo-Dobrovolskiy, 1974; Dolivo-Dobrovolskiy and Strelnikov, 1974; Shults, 1974; Jakovlev, et al, 1974; Jakovlev, Skublova, 1974).
- The Ustyurt region is a petroleum province and an area of weak neotectonic activity in the western part of the epipaleozoic Turanian Plate (Trifonov, et al, 1973; Makarov, et al, 1974; Makarov and Solovieva, 1975).

New subjects of study were introduced during the investigations; these include the area of modern volcanism in Kamchatka (Gusev, 1975; I.V. and P.V. Florensky, 1975); the southeastern part of the Russian platform (Florensky, et al, 1975); the Finnish-Scandinavian Shield (Dolivo-Dobrovolskiy and Strelnikov, 1975; Bogdanov et al, 1975); and Baikal region (Florenskaya, 1975). The results of studies in the Balkhash region were examined in the paleozoic folding areas of the Urals (Dolivo-Dobrovolskiy and Strelnikov, 1975) and Tuva (Luckashov, 1974). A comparison was carried out of the linears of the Western-Siberian epipalaeozoic and Eastern-Siberian Precambrian platforms (Astakhov and Eromenko, 1974). The late Quaternary tectonic activity of the Kopetdag lineaments were examined in the papers by Ivanova and Trifonov (1975), and by V.G. Trifonov (1975).

In the United States, Alaska, southern California, and Nevada were selected for study. These areas are extensive and represent a large variety of tectonic provinces, areas of volcanic activity, areas of seismicity, and mineral and petroleum provinces.

- Alaska is tectonically complex and forms a critical area for testing concepts of plate tectonics. Extensive mineral and petroleum provinces are also present in this state (Lathram and Albert, 1975; Lathram and Reynolds, 1975).
- Southern California is an area of high seismicity. Locations of epicenters during the past few years are known with high precision. Geologic indications of recent movements are also of value in establishing that faults observed in space imagery are active (Merifield and Lamar, 1975).
- Nevada is in the Basin-Range province and represents an area of block faulting, seismic activity and mineralization. The block faulting in this area is indicative of tensional characteristics (Rowan, 1974 and 1975).

Some geologic features are apparent on space and aerial imagery because of geologic control of topography and drainage, color of surface soil and rock materials, directions of foliation, and vegetation patterns. In addition, the scientists paid particular attention to the conditions of observation affect the ability to interpret geologic features. Such conditions include: sun elevation and direction, presence of thin snow cover, moisture, and spectral characteristics of the sensors.

II. Lineaments

Geological lineaments are visible on satellite images of the Earth and have aroused the interest of many geologists in a theoretical and economical sense. Observations from outer space provide the degree of generalization which makes it possible to interpret important features in the Earth's crust or to find certain interrelationships between the elements of subsurface geological structure, which had not been previously correlated.

In some regions, geological lineaments seen on space images were correlated with the age and the depth of deformations. The studies of Rowan (1975) showed that short, linear formations (not more than 10 km long) were connected mainly with quaternary tectonic activity and tend to mask more ancient structures.

Joint analysis of the results of the geological interpretation of space photographs, geological and geophysical data give evidence of the fact that "mega" linears are closely related to volcano-tectonics.

Dr. Lathram (1974 and 1975), carrying out special studies in Alaska, found that lineaments with a length less than 180 km mask some major structural features. His studies suggested that the largest structures with length of one hundred to several thousand kilometers, represent the surface expression of ancient, deep, geological structures reflected in deformations of the crust and possibly the upper mantle. Intermediate lineaments, the expanse of which fluctuates from 10 to 100 km, may be more recent.

Soviet specialists who studied the lineaments of the Caucasus, Tien Shan and the Turanian continental platform, obtained similar results, although they abstained from the conclusion that the length of the lineaments corresponds with their age, but concluded that because most long lineaments correspond to deep structural features and remain visible, they may have remained active throughout long periods of geological time, especially in orogenic regions (Makarov, et al, 1974; Makarov, Solov'eva, 1975; Anan'in, Trifonov, 1975).

In the Caucasus, NW-SE lineaments are prominent in the surface geological structure and are visible on space photographs with resolutions of 300-400 m. In addition, transverse lineaments are seen in this region, some of which correspond with breaks appearing on the surface. Others represent junctions between areas having a different tectonic structure or different thickness and facies of sedimentary rocks. Along these transverse lineaments there is evidence of late quaternary deformations and concentrations of mud volcanos. Some of the transverse lineaments correspond with fold

zones and breaks in the surface of the deeply buried crystalline base and also the surface of the Conrad. An analysis of seismic data shows that the zones of anomalous attenuation of seismic waves and zones having a high density of earthquake epicenters are narrow and correspond with some of the examined lineaments. Evidently, the latter reflect deformations at depths of 5-20 km.

On images received from the satellites of the "Meteor" system having a resolution of about 1 km, the majority of the lineaments examined above are poorly expressed or are not seen at all. NW-trending lineaments, however, are more clearly defined and mark the south slope of the Great Caucasus. According to the data of I.V. Anan'in and V.G. Trifonov (1975), this zone coincides with significant change of the Earth's crust thickness, and with the zone of powerful, and relatively deeper focused (10-60 km) earthquakes. Two of the NE-trending lineament zones are poorly expressed but have a relatively high density of the earthquake epicenters at depths of 20-30 km associated with them.

Two types of neotectonic formations are visible on the space images of Tien-Shan. The first is represented by basement folds which form ridges and intermountain basins. The second type is lineaments which differ in extent and direction (Trifonov, et al, 1973; Makarov, Solov'eva, 1975). V.I. Makarov and L.I. Solov'eva (1975) reached the conclusion that the most important attribute of the neotectonic structure of Tien-Shan and Turanian plate is its crossed character. It is believed that these faults or breaks formed simultaneously; however, the intensity of development varies in time and from place to place. According to geophysical, seismological and geological data, individual basement folds correspond to deformations in the crystal base and reach the Conrad discontinuity but their systems (anticlinoria and sinclinoria) reflect deformations in even deeper layers of the Earth's crust and upper mantle (Makarov, et al, 1974).

Space images of relatively high resolution, obtained from the manned spacecraft and Landsat, show very distinctly separate foundation (basement) folds and details of their inner ancient structure. Television images having low resolution (0.8-1.5 km) show only the up-warping and down-warping zones or systems which are the major elements of modern structure of this epiplatform orogenic belt.

A north-trending lineament in southwest Tien Shan, seen on a space photograph with a resolution of about 300-400 m, corresponds to an abrupt change in the depth of the folded basement. Television images of the same area revealed the NE-trending lineament undetected on the photograph about which we spoke before. This lineament corresponds to the western boundary of Tien-Shan and also corresponds to the zone of significant changes in crustal thickness. In addition it borders the area of high seismic activity and abnormal attenuation of seismic waves (Makarov, et al, 1974).

S.F. Skobelev, analyzing the space images of the Tadzhik basin--the wide folded area between Tien-Shan and Pamir ridges--arrived at a similar conclusion; the near-surface geological structure shows up well on the relatively large-scale images received from the "Soyuz-9" or from Landsat-1. These are the north-trending Neogen-quaternary folds and the faults. West-trending lineaments of Neogen-quaternary age stand out more clearly with decreased resolution. The locations of these features conform to geophysical anomalies and reflect deformations and the inhomogeneities in the crystalline basement and deeper layers (Makarov, et al, 1974).

L.C. Rowan (1974 and 1975) analyzed charts of Nevada showing the thickness of the Earth's crust deduced from seismic data and regional Bouguer gravity anomaly maps, and demonstrated that trends shown on these charts correspond with trends and locations of some lineaments interpreted from space images. The correlation of surface, linear formations with trends shown on charts of crustal thickness and gravity maps shows that some of these lineaments are related to deep structures.

The geophysical data in Alaska, while not conclusive, suggest that some lineaments may reflect deep nature of the large-scale structures, and in this sense, correspond to observations in Nevada. Some of the main lineaments of Alaska are known active breaks; others correspond to fault systems which were not known before interpretation of space images. Some features may be surface expressions of subduction zones (underthrusts) that were active in the geological past. Some investigators think that these zones represent boundaries of continental platforms and slow deformations may still be taking place but certainly greater movement took place in the Mesozoic era. Displacement of granitic bodies, foliation of the granites within the lineament zones, termination of the line of active volcanos at the lineaments, and seismic activity provide evidence for the deep seated nature of these features.

Southern Alaska, California and Nevada are seismically active. In California and Alaska, good correlations have been established between known, active faults and the linears interpreted from space images. Additional lineaments may represent active faults which should be studied. The study of Nevada includes analysis of well known lineaments related to the Basin and Range topography. Several of these fractures have been seismically active in historical time and served as epicenters for earthquakes, having magnitudes of as much as 7 on the Richter scale.

Correlation of linear features with surface geology and geophysical data is important for verification and evaluation of linear features. Some space-observed lineaments are reflected on aeromagnetic maps. Magnetic anomalies result from contrasting magnetic susceptibility or direction of remnant magnetization

in adjacent rock materials and may result from displacements in crystalline basement of crustal rocks or by the presence of intrusives. The depth to geologic materials that produce a magnetic anomaly is related to the width of the anomaly. Deep features produce wide anomalies, shallow features from narrow anomalies. Narrow linear features on magnetic maps often correspond to dikes. Rowan has observed both types in Nevada and believes that the largest linear features are related to deep crustal structures.

Florenskiy and Solov'eva interpreted small- and medium-scale space images of the Turanian Plate and found linear, oval, and isometrical photoanomalies, reflecting deformations of the Paleozoic folded basement surface as well as oldest layers of a significant sedimentary cover. According to M.A. Artamonov, E.N. Isaev, and P.V. Florenskiy, many faults and local up-warps of the basement, interpreted from space images, correspond to some geophysical anomalies, some of them reflecting the structure of the buried Paleozoic basement as well as of the deeper layers of the Earth's crust (Makarov, et al, 1974). Similar results were obtained from analyses of images of the Lower Volga Basin taken from Landsat-1 (Florenskiy, et al, 1975). It is important that some interpreted photoanomalies of the Turanian plate represent local buried uplifts that may be recommended for prospect for oil and gas.

In order to extract geological information from the highly cultivated scene, special photometric filtering methods were employed. The obtained image was compared with geological, gravimetric and magnetometer data. Geological maps did not reveal correlation with the photometric maps but the magnetometer and gravimetric data agree well with the photometric maps.

Many large lineaments correspond to some elements, of the magnetic and gravitational fields, such as zones of high change gradients and to boundaries between territories having different structural patterns.

A still clearer correlation was found between long lineaments and zones of high seismicity, increased stress as well as anomalous attenuation of seismic waves. Based on these data, some lineaments in Tien-Shan and in the Caucasus, are interpreted as deep-seated structures (Makarov, et al, 1974; Anan'in, Trifonov, 1975; Makarov, Solov'eva, 1975).

The association of large lineaments in the Caucasus and Kamchatka with volcanic activity further strengthens the belief that they extend to great depths (Trifonov, et al, 1973; Brusnichkina, Gusev, 1974 and 1975; Florenskiy I. and P., 1975).

The distribution of the known ore and petroleum deposits was compared with the linear features in Alaska and in Nevada (Lathram, 1975 and Rowan, 1975). These comparisons led to a very significant revision of maps of metallogenic provinces in these states. The continuation of the large-scale linear features from the land to the continental shelf of Alaska corresponds to boundaries of a known sedimentary basin may also have petroleum significance. Cook inlet, in Alaska, for example, where petroleum is being produced, is also bounded by lineaments visible on space images.

Studying the principal possibilities of transmitting the characteristics of deep structures of the Earth's crust to its surface, V.I. Makarov and L.I. Solov'eva (1975) came to a conclusion that there are two forms of transmission--methanical and geochemical. Various liquid-gas-products rise to the surface and effect the landscape, in some cases, by modifying the soil-plant cover, providing information both about the sources and about the layers through which they passed. The authors believe that space images may be used to identify lineaments that warrant field geochemical analysis.

III. Ring Structures

Oval or ring forms (several tens of kilometers up to 150 km) are seen on space images. They are recognized by anomalous patterns or tones on the image. Their boundaries are usually sharp. Sometimes the forms are not closed but are extended arc-shaped lines, intersecting sections of the image with a different tone and pattern.

The two types correspond to different components of the landscape and their combinations. The first type, local sections with an anomalous tone and pattern, usually correspond to small upheavals or depressions; the second has a complex, inhomogeneous, geomorphological structure. The common element of these two types is the character of the boundaries seen as curvilinear elements on the images. These boundaries correspond to elements of the relief, tectonic scarps, mountain ridges, elements of the drainage system and vegetation. The differences in the characteristics of the ring formations on the space images give evidence that we are dealing with two different types of ring structures.

Most often, small structures of the first type are observed. They are interpreted on space images of Kazakhstan, Tuva, Caucasus, Nevada, and other regions. Because of the number and magnitude of the recognized features and time limitations the investigators largely relied on published geologic maps and reports, although limited field studies and comparisons with existing geophysical and geochemical analyses were undertaken. Geological studies of such forms often indicate that they are caused by acid or basic intrusions and are related to volcanic activity (Lukashev, 1974; Martirosjan, Sakhatov, 1974; Rowan, Wetlawter, 1975; Carter, 1973). In some cases it is noted that volcanic rock thickness decreases with increasing of distance from such structures (Yakovlev, Skublova, 1974).

On the photos of modern volcanic regions (Kamchatka, Armenian volcanic plato) as ring structures are seen in the imagery of the volcanos (Brusnichkina, Gusev, 1974; Gusev, 1975; I. Florenskiy, P. Florenskiy, 1975). Usually, structures of the first type are well expressed in geophysics fields. In Kazakhstan, most of the interpreted ring structures correlate with gravily minima.

Combined analysis of the results of interpretation of space images, geological and geophysical data strongly suggest the volcano tectonic genesis of the majority of the first type formations.

A general conformity was observed between the number of linear elements and the existence of large ring structures. For example, the large number of lineaments are coincident with a ring structure with a diameter of about 150 km in Central Nevada. The age of the volcanics, associated with this ring formation, ranges between 19 to 30 million years. The general coincidence in age suggests a genetic relationship. Seismic and gravitational studies also show that the crustal depth under this structure is less as compared with surrounding areas.

These structures have metallogenic importance. Although there are examples of the confinement of ore deposits to places where the linear and annular structures intersect, they are rather rare. For example, a connection was found between erupted rocks, developed within some structures, and polymetallic mineralization (Lukashev, 1974). The authors suggest that the relative rareness of ore deposits is connected with the fact that they are buried under a layer of volcanic material.

The study of the spatial distribution of the annular volcano-tectonic structures permit possible solution of some problems of plate movements. The result of the analysis of the relationship among a series of annular structures in Air Plateau (North Africa) led N. Yakovlev and N. Skublova (1974) to express a hypothesis about a northerly movement of the African plate.

The larger ring structures interpreted on the small-scale space images, are the second type of the structures. In some cases, rocks in the central part of ring structures are older than rocks on the periphery, as noted by A. Dolivo-Dobrovol'skiy (1974) and A. Dolivo-Dobrovol'skiy and S. Strel'vikov (1975).

When studying the Chuysk block (southern Kazakhstan), A.V. Dolivo-Dobrovol'skiy (1974) found that some parts of the ring fault, limiting the ring structure, stand out well as gravitational and magnetic anomalies, connected with ultra basic intrusions. The edge of the ring structure divides the gravitational zone into two parts. This shift was not observed in surface geological features thus, we assume some lateral movements in the deeper layers of the Earth's crust. The ring structure was first found when interpreting a space photograph.

In the Urals, the boundaries of the ring structures are reflected by arc-shaped forms in the magnetic field. The distribution of the earthquake epicenters in this area is seemingly related to the same arc (Dolivo-Dobrovol'skiy, Strel'nikov, 1975) and some anomalous values of geothermal gradients are likewise related (in the eugeo-synclines of the Urals). The possibility of interpreting the location of geothermal anomalies connected with ring structures is of interest from the viewpoint of searching for sources of geothermal energy.

The large ring structures found on space images of the eastern part of Turanian plate are also shown on maps of the gravitational and magnetic fields. Their internal parts are characterized by negative anomalies and their outer parts by positive anomalies. Such structures may emerge due to isostatic leveling involving materials from the lower levels of the Earth's crust or from the upper mantle (Shults, 1974).

Very large ring structures (hundreds of kilometers in diameter) are also seen on mosaics of space images of the USA with a scale of 1:5,000,000 but their genesis remains unexplained (Carter, W.D., written communication).

As yet there is only limited evidence concerning the metallogenic values of the interpretations of large ring structures (Rowan, 1975). It can be assumed, however, that they represent zones of increased penetrability for mineralized solutions and melts and their importance, especially at points of intersection with lineaments, warrants further study.

The analysis of the fragments of the large ring structures together with the geological and geophysical data has been used for paleotectonic reconstruction (Bogdanov, Dolivo-Dobrovol'skiy, Lemanov, 1975), for example, the mutual position of the Kol'sky Peninsula and Karelia, in early Precambrian time have been interpreted. The study of large ring structures may well provide data for determining the movement of the lithospheric plates in different periods of the Earth's history.

Similar structures of the large type were mapped according to the materials from Landsat in the USA in the region of the Gulf Coast (Carter, 1973; Fischer, 1974). It is possible to assume a connection between these structures and the presence of salt domes or areas of salt withdrawal.

In Alaska, W. Fischer and E. Lathram (1974) found and mapped large elliptical structures in a region of sedimentary rocks. These structures may be connected with recent tectonics or with a change in the thickness of sedimentary covering and hence have petroleum significance.

CONCLUSIONS

OPTICAL AND PHOTOGRAPHIC ANALYSIS

Analysis undertaken of diffraction of images with curved, rather than wedge-filter edges, avoids edge diffraction effects and permits inexpensive enhancement or removal of selected geological lineaments on images and line maps.

Laser filtering can effectively remove obscuring trends but does not provide enhancement equal to that provided by electronic devices.

Rose-diagrams, suitable for the analysis of lineaments, can be made automatically by optical and photometric methods. A combined system employing rasters, density slicing, and optical defocusing has been developed in the Soviet Union for geological analysis of aerial and space images.

GEOLOGICAL ANALYSIS

Linear, ring and other features interpreted from space images often represent subsurface structure in the Earth's crust or upper mantle. They are expressed on the surface by disturbed zones containing faults, folds, facies changes, volcanos, deformations of relief and other features, such as the mud volcanos in the southeastern Caucasus.

Comparison of geophysical and geological data with linear and ring structures interpreted from space images is essential to established depths of earthquake epicenters and structural models of the crust. On the small-scale images (about 1:10,000,000), more deep-seated structural elements are reflected than on more large-scale ones (about 1:1,000,000). Aerial photographs and radar aerial photographs (of an order of 1:100,000) show surface and near-surface structures.

Lengths of interpreted structures tend to be proportional to depth. Giant (> 1000 km in length) lineaments and large-scale ring structures (> 100 km in diameter) represent structural elements traced to the lower levels of the Earth's crust and upper mantle. Lineaments of intermediate dimensions (from 200 km to 1000 km) may have deep-seated structural relationships. Small linear and ring formation are commonly younger crustal structures.

With the aid of space images, it seems possible to correlate structural elements to different levels of the lithosphere and, in specific cases, it was possible to relate structural disharmonies to different levels of the Earth's crust (Eastern Caucasus and Tien-Shan).

Assuming the correlation of size of structural features seen on space images with depth, it may be possible to define the boundaries of the lithospheric plates and to analyze, in time, deformations connected with shifts of the lithospheric plates in the part.

Interpreting images of different scales and resolutions appears to lead to the preliminary conclusion that images, varying by an order of magnitude, contain different information. On images with a scale of 1:10,000,000 with a resolution of about 1 km, we see the deepest and most ancient structures; on images with a scale of 1:1,000,000 with a resolution of about 100 m we see intermediate structures; and on photographs with a scale of 1:100,000 with a resolution of about 10 m, we see very recent tectonic formations.

For practical purposes, linears and ring structures are important for the following reasons:

- they may control the localization of mineral and fuel deposits,
- they may aid in outlining the metallogenic provinces,
- deformations may control localization of petroleum,
- they may indicate areas of seismic activity,
- they do add to our knowledge of the tectonic evolution of continental platforms, and
- they may be used for planning geological, geophysical and geochemical surveying work.

The present study, completed with the aid of the facilities of space technology, has not provided complete answers to questions relating to the deep-seated structures of the lithosphere. It is important to explain the mechanisms, by which the deep-seated linear and ring formations are revealed on the surface and by space images. In connection with this, the surface expression of lineaments

in topography, geochemical and other elements of the landscape require further study. At the present time, the exact correlation between the scales and the resolution of photographs and the depth of the linear and ring structures reflected on them has not been fully determined. Study of the regularity of spacing of lineaments over large areas of the Earth's surface, and a study of the possibilities for determining the character of the historical tectonic movements along the lineaments, should be studied and classification and terminology of lineaments should be jointly pursued. These studies create a basis for further collaboration of the USSR and the USA in areas of geological uses of space information.

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16 Abstract In 1971, a joint Soviet-American Working Group on Remote Sensing of the Natural Environment was established. It was organized into a number of discipline panels, one of which was on geology. Membership on this panel came from the Geological Survey of the United States and from the Institute of Geology of the USSR Academy of Sciences and the Ministry of Geology of the USSR. During the period 1971-1975, this panel conducted coordinated research in the use of space remote sensing data in the field of geology. This document presents a summary of that coordinated research effort.					
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